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6. AUTHOR(S)
DEMETRI P TELIONIS

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
VIRGINIA POLYTECHNIC INST ¢ STATE UNIVERSITY
BLACKSBURG, VA 24061-0219

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The most interesting finding was that for large angles of attack, a delta wing actually sheds vortices alternately, just like bluff bodies do. Also, at high sweep angles, vortex shedding is suddenly initiated at an angle of attack of 37 degrees. In addition, it was found that a seven-hole probe as small in diameter as 2% of the diameter of the vortex can actually precipitate breakdown, but with little effect on the static pressure on the wing suction surface.

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FINAL REPORT ON THE TRANSIENT DEVELOPMENT OF VORTICES OVER A DELTA WING

PROJECT # AFOSR–89–0283

prepared by

Demetri P. Telionis
Engineering Science and Mechanics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061–0219

1. INTRODUCTION

This program involves a very ambitious undertaking of constructing a model large enough to carry on board LDV and/or seven–hole probe instrumentation as wll as traversing mechanisms. Even more ambitious is the design and construction of a dynamic mount capable of carrying into dynamic motion a 50–lb model at frequencies up to 8 Hz. and plunging amplitudes of the order of 6 inches. Work on the latter was initiated with state funds in 1897. The project funded by AFOSR spanned the period of March to September 1990. Actually the AFOSR project was funded originally for two years. However, due to budget limitations, the government did not exercise the option of providing the second increment of funding which would have covered the period of October 1990 to March 1991.

Significant progress has been made in the construction of the Dynamic Mount. However, due to unforseen obstacles as described below this facility is not yet operational. On the other hand, progress has been made on the development calibration and checking of instrumentation. Research on the aerodynamics of delta wings at high angles of attack has also resulted in four publications.

1. FACILITIES & INSTRUMENTATION

Work on this project is conducted in the ESM wind tunnel. This tunnel has a 6 x 6 –foot test section with an excellent quality of flow. A description of this facility is included in one of the Appendices of the original proposal.

1.1 The Model

A delta wing model has been designed and constructed. The cost of the model overran the budgeted value by about 90% but even at a level of $14,000 the cost is believed to be very low, if compared with the cost of constructing such a model at a NASA laboratory.

This model is equipped with ports for pressure taps and ports to mount a sequence of Endevco transducers. Its upper side is constructed out of Acrylic which allows LDV laser beams to be shone from inside the model.

A miniature linear traverse was modified to carry the fiber–optic probe. Mirrors mounted on elements fixed or moving with the probe, allow displacement of the measuring volume normal or parallel to the model wall respectively. Two 7–hole probes were also constructed and calibrated. These instruments can be mounted by brackets on the same traverse system.

A system of mirrors mounting brackets and cylindrical lenses were mounted on the traversing system which opens the laser beams into a sheet of light which can also be shone from inside the model.

The unique capability of this design is that the LDV probe, the 7–hole probe and the laser sheet are all attached to the model and therefore follow it in its unsteady motion.

1.2 Fiber–Optic LDV System

Again with the support of the State, an entire LDV system was purchased which together with its peripherals and data acquisition system has costed approximately

$160,000. The unique feature of this system is that it combines sending and receiving optics in a 1"–diameter tube which is connected with the base of the system via fiber optics. A 2W Argon–Ion–laser beam is separated into blue and green beams, each of which is split in turn into two beams. These beams are passed through Bragg cells for frequency shifting. Fiber–optic couplers direct these beams into optical fibers which are connected with the fiber–optic probe. The signal is fed back through another optical fiber which is coupled with color separators and photomultipliers.

The signals are processed via TSI IFA processors. The entire operation is controlled by a System–2, Model 60 IBM computer which is dedicated to the system. Special software has been prepared to obtain store and manipulate the data. The computer also controls stepping motors for displacing the measuring volume.

The entire system has been tested extensively. Great difficulties were encountered with the proper method of seeding. A variety of techniques were tested; namely (a) a system of medical nebulizers connected by an especially designed and built manifold (b) Two theatrical foggers and (c) A system with orifices designed by NASA.

1.3 The Dynamic Model Mount

The wind tunnel facility will soon be equipped with a unique system, especially designed for the study of unsteady aerodynamics. The idea and the original design was inspired by concepts of supermaneuverablility and the launching of the AFOSR program on unsteady aerodynamics. It was decided to build a dynamic mount that could carry a 50 lb. model into plunging and pitching motions with frequencies of the order of 6 to 8 Hz. Later rolling motions were added to the design.

The opportunity to construct such an advanced system which would be unequaled to anything else in this country arose in 1987 with a State initiative to provide funds for instrumentation for University Laboratories. At that time, Dr. Simpson and the present author decided to join efforts and build up the potential of our excellent wind tunnel. We were able to secure $165,000 for the dynamic strut and $110,000 for a laser–Doppler velocimeter system with a fiber–optic LDV probe. The dynamic strut was Dr. Simpson's project and the LDV system was the present author's. The understanding was that the two, if combined, would make a formidable tool for research in unsteady aerodynamics. The two departments, Aerospace & Ocean Engineering and Engineering Science & Mechanics also agreed to cost–share about $15,000 each in machine shop work. A description of this facility, including all the specifications and most of the peripheral equipment can be found in the the attached AIAA paper.

Because of a severe constraint to spend the state money within a specified but short period, it was necessary to rush and order most of the key parts without having a complete design of the entire system. At first, work progressed very smoothly; expenses did not exceed the projected levels and it appeared reasonable to meet our target date of completion of Fall 1988.

Since the beginning of 1988, we had issued purchase orders for three high–pressure pumps. The linear actuator as well as the pitch–roll actuator were ordered through Moog Inc. and a preliminary design of the hydraulics was in place. Moog also made recommendations and provided specifications for parts and control elements that would meet proper operation and safety of the high–pressure hydraulic system. Purchase orders for such items were issued in February of 1988. Machining of major components progressed smoothly in 1988. However, one of the first complications arose when it was found out that machining of some parts of the supporting steel structure, the support of the four rods of the round–way bearings could not be completed in VPI machine shops and had to be sent out.

By August 1988, a massive concrete foundation (about 70,000 lbs of concrete) was in place. This required manual excavation and hauling of the concrete, because of the physcial constraints of space.

And then, in November of 1988, Moog admitted that they miscalculated in their design and indicated that the original supply line of one 2" piping was inadequate. This has been corrected by employing two 2" ports and Moog redesigned the manifold system of the vertical actuator. At the end of 1988, this actuator (3000 lb. weight) was delivered and put in place on a steel structure fabricated on campus, underneath the test section. Some additional time was lost studying the possibility of installing 3" lines and searching the market for uncommon and expensive fittings, but this idea was later abandoned. Until very recently, we were very concerned, with the proper size and quality of filters which would ensure a long life for all the hydraulic components which is the heart of the entire system.

At this stage, some problems were discovered with a newly–installed cooling system that the hydraulic system was supposed to be hooked on. Moreover, supplying power to the pumping station required the installation of new power lines, a transformer and other electrical equipment for power supply of 500 KVA. The cooling facility and power supply needs costed an extra $22,000 and further delayed the work.

During 1989, the steel structure which will support the vertical actuator was completed and tested. Moreover, it appeared necessary for both Depratments to contribute approximately $20,000 more each in machining work to complete the mount hardware and balance. All small hardware elements like brackets, stings, balance systems, etc. were thus machined. The three pumps and their peripherals were installed and housed in a special structure outside the tunnel. All hardware elements are thus completed. Most of the software that will control the system as well as data acquisition is also completed.

The changes in the design of the hydraulic system and the unexpected requirements to install water cooling facilities and power delayed the progress of the work and at the same time, drained our dwindling financial and manpower resources. On many occasions, we have been being forced to employ teams of our graduate students for time–consuming and hard manual labor. Moreover, these difficulties forced us to undertake lengthy battles with the state's bureaucracy.

The last hardware items (flanges and accessories) for the hydraulic system were ordered in June 1990. Tube fittings, quick disconnects, pressure gauges, diffusers and other accessories were purchased. Cooling water lines are connected to the power system.

According to our estimates, we have already invested in this facility including the fiber–optic probe, about $500,000. The original amount was increased by more state equipment funds as well as by overhead money of both departments. However, the Department of Aerospace & Ocean Engineering has definitely contributed the largest portion of the extra funds. The true value of the final product must be a multiple of the above figure. When Dr. Simpson requested estimates from private industry to contract the entire project out, the lowest offer was for $1,500,000.

2. RESEARCH ACCOMPLISHMENTS

In the early part of this effort, we investigated the properties of the flow about a delta wing at high angles of attack. This will essentially be the end condition of a pitch up motion.

In a subsequent effort we studied the coherence and stability characteristics of vortex cores and the interference of measuring devices with vortex breakdown characteristics. All this work has been discussed in detail in the publications which are attached. Only a short outline is therefore provided here. 340 → 240

The main thrust of the present project has not been attempted yet, due to the discontinuity in funding.

2.1 Vortex Shedding over Delta Wings

Our most interesting finding was that for large angles of attack, α, a delta wing actually sheds vortices alternately, just like bluff bodies do. One of the most intriguing findings is that for high sweep angles, vortex shedding is suddenly initiated at an $\alpha = 37°$. Moreover, the natural frequency of shedding is essentially independent of the Reynolds number. To communicate this finding quickly with the scientific community, we published the essential elements of this work in the form of a technical note[1]. A more complete version of this work was presented at the AIAA 20th Fluid Dynamics Plasma Dynamics & Lasers Conference in June 1989[2]. We are still working on flow visualization necessary to document completely these results, before a full paper is submitted for a journal publication.

The fundamental problem of the interaction of vortex sheets in three dimensions was further studied in a configuration which is essentially a delta wing at an angle of attack equal to 90°. This study concentrated on the fundamental character of the interaction of vortices with nonparallel axes. This work was presented at the Third International Congress of Fluid Mechanics in January 1990[3].

Laser–Doppler velocimetry data and seven–hole probe information was obtained on the delta wing model in the VPI Tunnel. The results map out in great detail the structure of the vortices. For the first time, this type of detailed information on pressure and velocity distributions is available for angles of attack as high as 40°. Moreover, a careful comparison of the accuracy of seven–hole information as well as its actual interference with the flow are obtained by a direct comparison with LDV data. It is found that a probe as small in diameter as 2% of the diameter of the vortex can actaully precipitate breakdown of its core. However, this phenomenon is confined to the core with rather little effect on the static pressure on the wing suction surface. These results will be discussed in detail in an AIAA paper which will be presented at the AIAA 29th Aerospace Sciences Meeting to be held in January 1991[4]. All these publications are attached to this report, and should be considered as an integral part of it..

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